Constraining the Right Handed Interactions from Pion Condensate Matter

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Abstract

We consider right handed neutrino emission from charged and neutral pion condensate matter likely to be present in the supernova core associated with SN 1987 A. This is used to constrain the strength of right handed interaction and we get excluded range of values for the right handed W boson and extra neutral Z' boson masses. For vanishing $W_L - W_R$ mixing we obtain $(1.3 - 1.8) \, M_{W_L} \approx \leq M_{W_R} \leq \approx 100 \, M_{W_L}$ and $(1.3 - 1.8) \, M_{W_L} \approx \leq M_{N'} \leq \approx 225 \, M_{W_L}$

PACS Nos. : 97.60.Jd, 21.65.+f, 3.15.-f, 96.60.Bw

1. Introduction

The microscopic composition of matter in the core of a neutron star can be very different from normal nuclear matter. The conditions in the core might be very close to those where meson condensates [1] could be formed, also there could be an abundance of quasifree pions [2] or a sufficiently large concentration of protons and hyperons [3] to allow direct URCA process to take place. The matter in the core may even undergo phase transition to its constitutent quark matter , giving rise to a strange matter core [4]. The exotic matter core has a effect of modifying the kinematic conditions of reactions. For example direct $\beta-$ decay is inhibited in neutron stars essentially because of simultaneous non conservation of energy and momentum owing to Fermi-Dirac statistical distribution. The presence of meson condensates or quasi free pions can supply the required momentum as is done by the spectator nucleon in the case of modified URCA process, similarly $\beta-$ decay of quarks and nucleons for large proton fraction in the core can take place. This would result in enhancement of energy loss rate. These exotic core compositions coupled with the emission of weakly interacting exotic particles and of neutrinos with non-standard properties and couplings would have the consequence of potentially shortening the duration of the neutrino burst from the core of a newly born, hot neutron star associated with the early cooling phase of SN 1987 A. This has been used to put stringent constraints on the properties and couplings of exotic particles and on Dirac mass, anamolous magnetic moment, right handed interactions *etc.* of neutrinos $[5-9]$. Recently, axion emission from meson condensate matter has been invoked [10] to explain the cooling mechanisms for some sources like PSR $0833-45$, PSR $0856+14$, γ ray pulsar Gemingo and stars whose observed surface temperatures are different from what could be predicted in the standard cooling scenario.

In this paper, we assume the presence of charged and neutral pion condensates

in the core and consider the emission of light right handed neutrinos *via* right handed charged and neutral current interactions as in left-right symmetric models of weak interactions [11] or in some super-string inspired models [12]. Such a right handed neutrino can be produced in the standard supernova core through electron capture, pair annihilation or neutrino pair bremmstrahlung processes: $e^- + p \longrightarrow n + \nu_R$, $e^+ + e^- \longrightarrow \nu_R + \bar{\nu}_R$, $n + n \longrightarrow n + n + \nu_R + \bar{\nu}_R$ and $n + n \longrightarrow n + p + e^- + \bar{\nu}_R$. On account of high electron degeneracy and low proton fraction the first two processes are somewhat suppressed. In the presence of charged and neutral pion condensates, we have the following reactions producing right handed neutrinos:

$$n + \pi^- \longrightarrow n + e^- + \bar{\nu}_R \qquad (1a)$$

$$n + \pi^0 \longrightarrow p + e^- + \bar{\nu}_R \qquad (1b)$$

$$n + \pi^0 \longrightarrow n + \nu_R + \bar{\nu}_R \qquad (1c)$$

along with similar processes involving protons in the initial state. In the presence of kaon condensed matter analogous reactions involving kaons will also contribute to the production of right handed neutrinos but will be Cabbibo suppressed. Here we will not consider these processes.

In section 2, we calculate the right handed neutrino emissivity and in section 3, we address the question of neutrino opacity and calculate its mean free path in the presence of charged and neutral pion condensates. The integrated luminosity is then used in section 4 to put an upper bound on the strength of right handed charged and neutral interactions. The lower bound is obtained by the consideration of neutrino trapping in the core.

2. Calculation of Neutrino Emissivity

The effective weak interaction Hamiltonian describing the processes (1) in the left-right symmetric model [12] is given by

$$\mathcal{H}_{\mathcal{W}} = \frac{G_R}{\sqrt{2}} \, J^h_{R\mu} \, L^\mu_R \tag{2}$$

where $G_R^2 = BG_F^2$ with $B = \xi^2 + M^2_{W_L}/M^2_{W_R}$ for the charged current and $G_R^2 = B'G_F^2$ with $B' = \xi^2 + M^2_{W_L}/M^2_{N'}$ for the neutral current, G_R is the strength of right handed current, ξ is the mixing parameter, M_{W_R} is the mass of the right handed W boson and $M_{N'}$ is the effective mass of right handed Z boson, $J^h_{R\mu}$ and L^μ_R are the hadronic and leptonic currents respectively. The charged hadronic weak current is written as

$$J^{hc}_{R\mu} = V^1_\mu + A^1_\mu + i\left(V^2_\mu + A^2_\mu\right) \tag{3}$$

along with neutral hadronic weak current as

$$J^{h0}_{R\mu} = \frac{1}{\cos^2\theta_W}\left[V^3_\mu + A^3_\mu \cos 2\theta_W - J^{e.m.}_\mu \sin^2\theta_W\right] \tag{4}$$

2.1 Charged pion Condensate

The charged pion condensed phase is constructed by a chiral rotation by the unitary operator [13]

$$U\left(\pi^c; \mu_\pi, k_c, \theta\right) = exp\left(i \int d^3r \, \chi V_3^0\right) exp\left(iQ_1^5\theta\right) \tag{5}$$

with $\chi = k_c \cdot r - \mu_\pi t$ acting on the ground state. This generates the charged pion condensed phase with a macroscopic charged pion field of chemical potential μ_π, momentum k_c and chiral angle θ. The participating particles for ν_R emission are the quasiparticles η and ζ, which are superposition of the proton and neutron states:

$$\left|\eta(p, \pm 1)\right\rangle = \cos \phi_c \left|n(p + k_c, \pm 1)\right\rangle \mp i \sin \phi_c \left|p(p + k_c, \pm 1)\right\rangle$$

$$\left|\zeta(p, \pm 1)\right\rangle = \cos \phi_c \left|p(p - k_c, \pm 1)\right\rangle \pm i \sin \phi_c \left|n(p - k_c, \pm 1)\right\rangle \tag{6}$$

where $+(-)$ refers to spin up (down), and ϕ_c is the mixing angle given by

$$\phi_c = \left(\frac{g_A k_c}{\mu_\pi}\right)\theta + O(\theta^2),$$

g_A being the axial vector coupling constant. The matrix element squared and summed over spins is given by

$$\sum |M|^2 = H_{\mu\nu} L^{\mu\nu} \tag{7}$$

with

$$H_{\mu\nu} = \sum_{s_1, s_2} \left\langle\eta(p_2, s_2)\big|\tilde{J}_\mu^h\big|\eta(p_1, s_1)\right\rangle\left\langle\eta(p_2, s_2)\big|\tilde{J}_\nu^h\big|\eta(p_1, s_1)\right\rangle^\dagger$$

$$L^{\mu\nu} = 8\left(q_1^\mu q_2^\nu + q_1^\nu q_2^\mu - q_1 \cdot q_2 g^{\mu\nu} - i\epsilon^{\mu\nu\alpha\beta} \, q_{1\alpha} q_{2\beta}\right).$$

Here $\tilde{J}_\mu^h$ is the rotated hadronic current and is obtained by applying chiral rotation U of equation (5) to J_μ^h in order to include effect of charged pion condensate, p_1, p_2

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are the four momenta of incomming and outgoing quasiparticles and q_1, q_2 are the four momenta of leptons.

The ν_R emission process in charged pion condensate can now be studied in terms of quasiparticles. The process

$$\eta \longrightarrow \eta + e^- + \nu_R \tag{8}$$

is mediated by weak flavor changing charged current given in equation (3). Applying the chiral rotation (5) we get

$$\tilde{J}_{R\mu}^{hc} = U \, J_{R\mu}^{hc} \, U^{-1}$$

$$= e^{i\chi} \left[V_\mu^1 + A_\mu^1 + i \cos\theta \left(V_\mu^2 + A_\mu^2 \right) + i \sin\theta \left(V_\mu^3 + A_\mu^3 \right) \right] \tag{9}$$

In terms of this rotated current the square of the quasiparticle $\beta-$decay matrix element, summed over spins can be obtained as

$$\sum |M|^2 = 2\, G_R^2 \,\theta^2 \left[1 + \frac{g_A^2 k_c^2}{\mu_\pi^2} \right] \left[\left(1 + 3g_A^2 \right) \omega_1 \omega_2 + \left(1 - g_A^2 \right) \bar{q}_1 \cdot \bar{q}_2 \right] \tag{10}$$

where $q_i(\omega_i, \bar{q}_i)$ correspond to the four momentum of ν_R and electron for $i = 1, 2$ respectively. The emissivity for this process is given by

$$\dot{\mathcal{E}} = \prod_{i=1}^{2} \left[\int \frac{d^3 p_i}{(2\pi)^3} \right] \prod_{j=1}^{2} \left[\int \frac{d^3 q_j}{2\omega_i (2\pi)^3} \right] (2\pi)^4 \delta^4 \left(p_1 + k_c - p_2 - q_2 - q_1 \right)$$

$$\omega_1 f(p_1) \left[1 - f(p_2) \right] \left[1 - f(q_2) \right] \tag{11}$$

Treating the nucleons to be relativistic and nondegenerate and electrons to be degenerate, all phase space integrals (11) can be done analytically except one and we get

$$\dot{\mathcal{E}} = \frac{G_R^2 \, n_N \, \theta^2}{(2\pi^3)} \, T^6 \left(1 + 3g_A^2 \right) \left(1 + \frac{g_A^2 k_c^2}{\mu_\pi} \right) I\left(\frac{\mu_\pi}{T}, \frac{\mu_e}{T} \right)$$

$$\simeq 1.6 \times 10^{34} B \, \theta^2 \, T_{10}^6 \, \rho_{14} \left(1 + 3g_A^2 \right)$$

$$\times \left(1 + \frac{g_A^2 k_c^2}{\mu_\pi^2} \right) \left(\frac{938 MeV}{m_N^*} \right) I \qquad \text{ergs cm}^{-3}\,\text{s}^{-1} \tag{12}$$

where n_N is the number density of nucleons in the core, ρ_{14} is the core density in units of 10^{14} gms/cc, T_{10} is the temperature of the core in units of 10 MeV, m_N^* is the effective mass of the nucleon and

$$I = \int\limits_0^\nu \frac{x^3 \left(\mu/T - x\right)^2}{e^{(x-\nu)} + 1}\, dx$$

with $\nu = \left(\mu_\pi - \mu_e\right)/T$.

The other dominant process

$$\zeta \longrightarrow \eta + \nu_R + \bar{\nu}_R \tag{13}$$

which is mediated by the weak right handed neutral current (4) which under chiral rotation becomes

$$\tilde{J}_{R\mu}^{h0} = \frac{1}{\cos^2\theta_W}\left[\left(V_\mu^3 + A_\mu^3 \cos 2\theta_W\right)\cos\theta + \left(A_\mu^2 + V_\mu^2 \cos 2\theta_W\right)\sin\theta \right.$$
$$\left. - \sin^2\theta_W \left(\frac{1}{2}V_\mu^Y + V_\mu^3 \cos\theta + A_\mu^3 \sin\theta\right)\right] \tag{14}$$

The relevant part of the matrix element squared and summed over spins is given by

$$\sum |M|^2 = 2\,G_R^2 \left[3g_A^2\theta^2 + \left(\frac{g_A k_c}{\mu_\pi}\theta + \frac{\cos 2\theta_W}{\cos^2\theta_W}\right)^2\right]\omega_1\omega_2 \tag{15}$$

and the emissivity is calculated to be

$$\dot{\mathcal{E}} = \frac{G_R^2}{240\pi^3}\, n_N\,\mu_\pi^6 \left[3g_A^2\theta^2 + \left(\frac{g_A k_c}{\mu_\pi}\theta + \frac{\cos 2\theta_W}{\cos^2\theta_W}\right)^2\right]$$
$$\simeq 6.5 \times 10^{41}\, B'\,\rho_{14} \left(\frac{938 MeV}{m_N^*}\right)\left(\frac{\mu_\pi}{250 MeV}\right)^6$$
$$\times \left[3g_A^2\theta^2 + \left(\frac{g_A k_c}{\mu_\pi}\theta + \frac{\cos 2\theta_W}{\cos^2\theta_W}\right)^2\right] \qquad \text{ergs cm}^{-3}\,\text{s}^{-1} \tag{16}$$

2.2 Neutral Pion Condensate

Like the charged pion condensed phase, neutral pion condensed phase is constructed by a chiral rotation of the ground state with the unitary operator [10, 14]

$$U(\pi^0, \phi) = exp\left(i \int d^3r \, A_3^0 \, \phi\right) \tag{17}$$

here ϕ is the classical pion field chosen to be of the form $\phi = A \sin k_0 z$ where A and k_0 are the amplitude and momentum of the condensate respectively. In this case the pion condensate forms a standing wave in one dimension which is in $\hat{Z}$ direction. Following reference [10], the wavefunction for nucleon quasiparticle states are given by

$$\left|\tilde{N}(p, \pm 1)\right\rangle = \left|N(p, \pm 1)\right\rangle \mp \frac{A\kappa_0}{2} \left[\frac{\left|N(p+k_0, \pm 1)\right\rangle}{\epsilon_N(p+k_0) - \epsilon_N(p)} \right.$$
$$\left. + \frac{\left|N(p-k_0), \pm 1\right\rangle}{\epsilon_N(p-k_0) - \epsilon_N(p)} \right] + O(A^2) \tag{18}$$

where ϵ_N is the single particle nucleon energy, and κ_0 represents the modified pseudo-vertex [10]. The hadronic tensor $H^{\mu\nu}$ is written as

$$H^{\mu\nu} = \sum_{s_1, s_2} \left|B_{s_1, s_2}\right|^2 H^{\mu\nu}_{s_1, s_2} \tag{19}$$

where

$$B_{s_1, s_2} = \int d^3r \, \phi^*_{s_2, p_2}(r) \, \phi_{s_1, p_1}(r) \, e^{-i(q_1+q_2)\cdot r}$$

and

$$H^{\mu\nu}_{s_1, s_2} = \left\langle \chi^N_{s_2} \middle| \tilde{J}^\mu_h \middle| \chi^N_{s_1} \right\rangle \left\langle \chi^N_{s_2} \middle| \tilde{J}^\nu_h \middle| \chi^N_{s_1} \right\rangle^\dagger.$$

We now consider the process

$$\tilde{n} \longrightarrow \tilde{p} + e^- + \bar{\nu}_R \tag{20}$$

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mediated by weak right handed flavor changing charged current which under rotation by the unitary matrix (17) becomes

$$\tilde{J}^{hc}_{R\mu} = e^{i\phi}\left[V^1_\mu + A^1_\mu + i\left(V^2_\mu + A^2_\mu\right)\right] \tag{21}$$

Thus the hadronic current remains unchanged on the chiral rotation and the momentum is supplied by the current and wavefunction both. The matrix element squared and summed over spins for the above process is given by

$$\sum|M|^2 = \frac{4G_R^2 g_A^2 (2\pi^3) A^2 \kappa_0^2}{\left(\omega_1 + \omega_2\right)^2}\left[\delta^3(\bar{\beta} + \bar{k}_0) + \delta^3(\bar{\beta} - \bar{k}_0)\right]\omega_1\omega_2 \tag{22}$$

where $\bar{\beta} = \left(\bar{p}_1 - \bar{p}_2 - \bar{q}_2 - \bar{q}_1\right)$. The emissivity now becomes

$$\dot{\mathcal{E}} = \frac{G_R^2\, g_A^2\, \kappa_0^2\, A^2}{4\,\pi^3\,(\mu_\pi - \mu_e)^2}\, n_N\, T^6\, I\!\left(\frac{\mu_\pi}{T}, \frac{\mu_e}{T}\right)$$

$$\simeq 2.2 \times 10^{34} B\, g_A^2\, T_{10}^6\, \rho_{14}\left(\frac{A^2}{0.1}\right)\left(\frac{\kappa_0}{\mu_\pi - \mu_e}\right)^2\left(\frac{938 MeV}{m_N^*}\right) I\, \text{ergs}\, \text{cm}^{-3}\, \text{s}^{-1} (23)$$

where κ_0, $(\mu_\pi - \mu_e)$ are in units of MeV, μ_e bieng the electron chemical potential.

The right handed neutrino pair emission process

$$\tilde{n} \longrightarrow \tilde{n} + \nu_R + \bar{\nu}_R \tag{24}$$

is mediated by weak right handed neutral current which after chiral rotation becomes

$$\tilde{J}^{h0}_{R\mu} = \frac{1}{\cos^2\theta_W}\left[\left(V^3_\mu + A^3_\mu \cos\theta_W\right)\cos\theta\right.$$

$$\left. + \left(V^2_\mu \cos 2\theta_W + A^2_\mu\right)\sin\theta - \left(\frac{V^Y_\mu}{2} + V^3_\mu \cos\theta + A^3_\mu \sin\theta\right)\right] \tag{25}$$

Unlike the charged current, here the momentum is supplied only by the wave function. The matrix element squared summed over spins is given by

$$\sum|M|^2 = \frac{32\pi^3 G_R^2 g_A^2 A^2 \kappa_0^2 \cos^2 2\theta_W}{\cos^4\theta_W\left(\omega_1 + \omega_2\right)^2}\left[\delta^3(\bar{\beta} + \bar{k}_0) + \delta^3(\bar{\beta} - \bar{k}_0)\right]\omega_1\omega_2 \tag{26}$$

and emissivity is calculated to be

$$\dot{\mathcal{E}} = \frac{G_R^2 \cos^2 2\theta_W}{15\pi^3 \cos^4 \theta_W} g_A^2 A^2 \kappa_0^2 \mu_\pi^4 n_N$$

$$\simeq 2.5 \times 10^{41} B' g_A^2 \rho_{14} \left(\frac{A^2}{0.1}\right) \left(\frac{\mu_\pi}{250 MeV}\right)^4 \left(\frac{938 MeV}{m_N^*}\right) \quad \text{ergs cm}^{-3} \text{s}^{-1} \quad (27)$$

3. Neutrino Trapping

Let us now estimate the mean free path of right handed neutrinos in the presence of charged and neutral pion condensed matter, likely to be present in the core. The important reactions that contribute to the neutrino mean free path are the neutrino absorption processes

$$\nu_R + \eta \longrightarrow \eta + e^- \tag{28}$$

and

$$\nu_R + \tilde{n} \longrightarrow \tilde{p} + e^- \tag{29}$$

In addition we have the ν_R scattering processes

$$\nu_R + \tilde{N} \longrightarrow \nu_R + \tilde{N} \tag{30}$$

in neutral pion condensate. The first two processes are mediated by charged current and the last one by neutral current. The absorption length $l(\omega_\nu, T)$ for a right handed neutrino of energy ω_ν in a medium of temperature T is defined as [15]

$$l^{-1}(\omega_\nu, T) = \frac{1}{(2\pi)^5} \int d^3 p_1 \int d^3 p_2 \int d^3 p_e \sum |M|^2 \delta^4 (p_1 + q_\nu - k - p_2 - q_e)$$

$$\times \left[1 - f(\omega_e, \mu_e)\right] \left[1 - f(E_2, \mu_2)\right] f(E_1, \mu_1) \tag{31}$$

Using $\sum |M|^2$ derived in section 2, we get

$$
l^{-1} = \frac{G_R^2}{2\pi} \left(1 + 3g_A^2\right) \left(1 + \frac{g_A^2 k_c^2}{\mu_\pi^2}\right) \theta^2 \, n_N \left(\omega_\nu + k_0\right)^2 \left[1 + e^{\left(\mu_e - \mu_\pi - \omega_\nu\right)/T}\right]^{-1}
$$

$$
\simeq 0.32 \, B \, \rho_{14} \left(1 + 3g_A^2\right) \left(1 + \frac{g_A^2 k_c^2}{\mu_\pi^2}\right) \left(\frac{\theta^2}{0.1}\right)
$$

$$
\times \left(\frac{938 MeV}{m_N^*}\right) \left[1 + e^{\left(\mu_e - \mu_\pi - \omega_\nu\right)/T}\right]^{-1} \quad \mathrm{m}^{-1} \tag{32}
$$

$$
l^{-1} = \frac{G_R^2 \, A^2 \, \kappa_0^2 \, g_A^2}{2\,\pi} \, n_N \left(\frac{\omega_\nu + k_0}{2\omega_\nu + \mu_\pi^0}\right)^2 \left[1 + e^{\left(\mu_e - \mu_\pi^0 - \omega_\nu\right)/T}\right]^{-1}
$$

$$
\simeq 1.2 \, B \, \rho_{14} \left(\frac{A^2}{0.1}\right) \left(\frac{\kappa_0}{104.57 MeV}\right)^2 \left(\frac{938 MeV}{m_N^*}\right)
$$

$$
\times \left(1 - \frac{\omega_\nu}{\mu_\pi^0 + 2\omega_\nu}\right) \left[1 + e^{\left(\mu_e - \mu_\pi^0 - \omega_\nu\right)/T}\right]^{-1} \quad \mathrm{m}^{-1} \tag{33}
$$

for processes (28) and (29) respectively. For the scattering process, the mean free path is likewise calculated to be

$$
l^{-1} = \frac{4 \, G_R^2 \, g_A^2 \, A^2 \, \kappa_0^2 \, n_N \, \cos^2 2\theta_W}{\pi \, \cos^4 \theta_W} \left(1 + \frac{\omega_\nu}{\omega_\nu + \mu_\pi}\right)^{-2}
$$

$$
\times \left[1 + e^{-\left(\mu_\pi^0 + \omega_\nu\right)/T}\right]^{-1}
$$

$$
\simeq 4 \, B' \, \rho_{14} \left(\frac{A^2}{0.1}\right) \left(\frac{\kappa_0}{104.57 MeV}\right)^2 \left(\frac{938 MeV}{m_N^*}\right)
$$

$$
\times \left(1 + \frac{\omega_\nu}{\mu_\pi^0 + 2\omega_\nu}\right)^{-2} \left[1 + e^{-\left(\mu_\pi^0 + \omega_\nu\right)T}\right]^{-1} \quad \mathrm{m}^{-1} \tag{34}
$$

4. Results and Discussions

An estimate of the allowed range of the right handed current interactions can be made by the following considerations. If the neutrino absorption length happens to be greater than the core radius, then ν_R streams out freely cooling the core faster. As G_R increases, the flux for ν_R also increases. Hence the total integrated luminosity along with the constraint that the total energy available for emission *via* ν_R associated with SN 1987 A cannot exceed $2 - 4 \times 10^{53}$ ergs and that ν_R alone should not cool the core in the time scale less than $5 - 10\,sec.$, set an upper bound on G_R. On the other hand if the neutrino mean free path is less than the radius of the core , they would then be trapped and thermalised emission of ν_R would now proceed through standard thermal diffusion process from right handed neutrino sphere. In this case as has been discussed by Barbieri and Mohapatra [8], energy loss *via* ν_R will dominate unless G_R satisfies certain lower limit. These constraints on the strength of right handed interaction translates into a range of excluded values of M_{W_R} and $M_{N'}$.

From the above consideration the upper limit on G_R for charged current interactions is obtained from equations $(12, 23)$ and for the neutral current interaction from equations $(16, 27)$. For the trapping to occur we see from equations $(28 - 30)$ that $B \geq 4 \times 10^{-6}$ and following the reference [8] we obtain the lower limit on G_R. These limits tranlate into an excluded range of M_{W_R} and $M_{N'}$ masses. For Charged current interaction the excluded range is given by

$$10^{-4} \approx \leq \left[\xi^2 + \frac{M_{W_L}^2}{M_{W_R}^2} \right]^{\frac{1}{2}} \leq \approx 0.1 - 0.3$$

and for the neutral current interaction

$$1.41 \times 10^{-5} \approx \leq \left[\xi^2 + \frac{M_{W_L}^2}{M_{N'}^2} \right]^{\frac{1}{2}} \leq \approx 0.1 - 0.3$$

In the absence of $W_L - W_R$ mixing, the excluded range for M_{W_R} and $M_{N'}$ become $(1.8 - 3.1)\,M_{W_L} \approx \leq M_{W_R} \leq \approx 100\,M_{W_L}$ and $(1.8 - 3.16)\,M_{W_L} \approx \leq M_{N'} \leq$

$\approx 225\, M_{W_L}$ We find that in the presence of pion condensate in the core of the nascent neutron star the upper bound on the excluded region for $M_{N'}$ is stronger in comparision to that of reference [8].

5. Acknowledgement

6. References

1. J. Kogut and J.T. Manassah, Phys. Lett. **41**, 129, (1972); A.B. Migdal, Phys. Rev. Lett. **31**, 247, (1973); R.F. Swayer and D.J. Scalpino, Phys. Rev. **D7**, 953, (1973); R.F. Dashen and J.T. Manassah, *ibid*, **12**, 979, (1975); **12**, 1010, (1975); G. Baym, D. Campbell, R. Dashen and J. Manassah, Phys. Lett. **B58**, 304, (1975); D.B. Kaplan and A.E. Nelson, Phys. Lett. **B175**, 57, (1986); *ibid* , **B179**, 409E, (1986); G.E. Brown, K. Kubodera and M. Rho, *ibid* **B192**, 273, (1987); T. Muto and T. Tatsumi, *ibid* **B283**, 165, (1992); G.E. Brown, K. Kubodera, M. Rho and V. Thorrsson, *ibid* **B291**, 355, (1992).

2. R. Mayle, D.N. Schramm, M.S. Turner and J.R. Wilson, Phys. Lett. **B317**, 19, (1993); B. Friedman, V.R. Pandharipande and Q.N. Usmani, Nucl. Phys. **A372**, 483, (1981).

3. J.M. Lattimer, C.J. Pethick, M. Prakash and P. Haensal, Phys. Rev. Lett. **66**, 2701, (1991); M. Prakash, M. Prakash, J.M. Lattimer and C.J. Pethick, Astrophys. J. Lett. **390**, 77, (1992); D. Page and J.H. Applegate, Astrophys. J. Lett. **394**, 117, (1992).

4. G. Byam and S. Chin, Phys. Lett. **B62**, 241, (1976); E. Witten, Phys. Rev. **D30**, 272, (1984); E. Farhi and R.L. Jaffe, Phys. Rev. **D30**, 2379, (1984).

5. G. Raffelt and D. Seckel, Phys. Rev. Lett. **60**, 1793, (1988).

6. M.S. Turner, Phys. Rev. **D45**, 1066, (1992); A. Burrows, R. Gandhi and M.S. Turner, Phys. Rev. Lett. **68**, 3834, (1992); A. Goyal and S. Dutta, Phys. Rev **D49**, 3910, (1994).

7. J.M. Lattimer and J. Cooperstein, Phys. Rev. Lett. **61**, 23, (1988); A. Goyal,S. Dutta and S.R. Choudhury , Phys. Lett. **B346**, 312, (1995).

8. R. Barbieri and R.N. Mohapatra, Phys. Rev. **D39**, 1229, (1989).

9. N. Iwamoto, Phys. Rev. Lett. **53**, 1198, (1984); N. Iwamoto, Phys. Rev. **D39**, 2120, (1989); M.S. Turner, Phys. Rep.**197**, 67, (1990); G. Raffelt, Phys. Rep. **198**, 1, (1990).

10. T. Muto, T. Tatsumi and N. Iwamoto, Phys. Rev. **D50**, 6089, (1994).

11. *e.g.* see review, R.N. Mohapatra 'Quarks, Leptons and Beyond', Proceedings of NATO Advanced Study Institute, Munich, West Germany (1983), edited by H. Fritzsch *et.al* (NATO ASI, series **B**, Vol. **122**, (plenum New York, 1985).

12. J.Ellis and K.Olive Phys. Lett. **B193**, 525, (1987); M. Turner, Phys. Rev. Lett.**60**, 1699, (1988); R. Mayle *et.al.*, Phys. Lett. **B203**, 198, (1988); R. Barbieri and R.N. Mohapatra, Phys. Rev. Lett. **61**, 27, (1988); *e.g.* see R.N. Mohapatra and P.B. Pal, 'Massive Neutrinos in Physics and Astrophysics', World Scietific, (1993).

13. O. Maxwell, G.E. Brown, D.K. Campbell, R.F. Dashen and J.T. Manassah, Astrophys. J. **216**, 77, (1977).

14. T. Tatsumi, Prog. Theor. Phys. **69**, 1137, (1983); H. Umeda, K. Nomoto, S. Tsuruta, T. Muto and T. Tatsumi, Astrophys. J. **431**, 309, (1994); T. Tatsumi, Prog. Theor. Phys. **80**, 22, (1988).

15. R.F. Sawyer and A. Soni, Astrophys. J. **216**, 73, (1977).